THE NATURE OF THE EVOLUTION OF FUNDAMENTAL POTENTIALITIES IN THE PLANT KINGDOM[1]

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When one studies the plant kingdom in all of its more important aspects, he becomes aware of the fact that he is dealing with a remarkably consistent system, extending from very simple units on the lowest level to aggregates of exceedingly complex units on the highest level. The most remarkable facts in evidence are that the fundamental potentialities are added step by step as one follows up the ascending scale of complexity, that when once added these fundamental potentialities are not lost but are carried up to the highest levels of the plant series, and that therefore the plants of any general stage or subkingdom all possess a complement of similar fundamental potentialities. The plants of any subkingdom contain the complete complement of fundamental potentialities acquired in the forward evolution of the whole series to the given level.

From a practical and theoretical survey of the plant kingdom it becomes clearly evident that we can recognize ten progressive stages or subkingdoms. These stages are quite distinct and easily delimited from each other. Seven of them are represented by living forms and three are either theoretical or represented only by fossils. There are seven subkingdoms of living plants, no more and no less. One hundred general potentialities, represented by important structures or activities, have been segregated and listed below for the entire plant series. They are the potentialities which are most in evidence from the general viewpoint. Others could be listed, but they would not necessarily assist in making clearer the fundamental facts and principles involved.

The mechanisms in which these fundamental potentialities are contained are in the protoplast, but are not to be confused with genosomes having the potentialities for the genes of Mendelian heredity. In most cases the mechanisms may be conceived of as being complex systems of autogens scattered throughout the entire protoplast or a large part of it. Where in the protoplast, for example, is the mechanism causing the

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process of respiration? What is the nature of the protoplasmic pattern which determines the character and sequence of the twelve fundamental stages in the typical antithetic alternation of generations life cycle characteristic of all higher plants from the liverworts on up? What kind of a grouping of genosomes would determine that in the Bryophytes and Homosporous Pteridophytes the sexual state is always normally determined in the gametophyte, the sporophyte being a neutral generation, while when one passes up to the middle level of the Pteridophytes he finds that the sexual state is always determined in some stage of the sporophyte ontogeny throughout all the phyletic lines up to the highest seed plants? For such questions our present-day genetics has no answers. In fact, our present-day genetics is but a superficial discipline. These fundamental processes and characteristics are a part of the universal heredity of the plant much more important in the study of the general evolution and taxonomy of plants than all the superficial Mendelian genes, so far discovered, combined. For the present we may then simply assume that the protoplasmic mechanisms responsible for the fundamental potentialities are complex patterns of autosomes pervading in most cases at least the entire protoplast, although some may be confined to the nucleus only.

The ten subkingdoms are given below in connection with the one hundred fundamental potentialities. The fact of a definite, progressive, accumulative process in the evolution of the plant kingdom was presented in a general but incomplete way in two earlier papers. See "Principles of Plant Taxonomy, X" (Ohio Jour. Sci. 31: 77–96, 1931) and "Phylogenetic Taxonomy of Plants" (Quart. Rev. Biol. 9: 129–160, 1934).

ONE HUNDRED PROGRESSIVELY ACCUMULATED FUNDAMENTAL POTENTIALITIES EVOLVED IN THE PLANT SERIES, ARCHEOPHYTA TO ANGIOSPERMAE

In the progressive evolution of the plant kingdom, the fundamental potentialities acquired or changed to a more advanced condition are apparently never lost and very rarely inhibited in any group of organisms.

I. ARCHEOPHYTA. Biont stage; theoretical. The first five potentialities listed below are attributes of all plant and animal organisms.

1. With the genesis of living things or bionts there came into existence autogens possessing the power of assimilation or self-perpetuation. These autogens may be conceived of as definite patterns or

systems of molecules forming colloidal particles and having the power to duplicate themselves in their own field from the surrounding atoms, ions, and molecules.

2. The potentiality of self-division of the autogens with the two daughter particles retaining all the potentialities of the mother autogen.

3. The power of mutation, through which from time to time an individual autogen is changed to a new pattern with new potentialities.

4. Autogens of two or more kinds with the power of correlative interaction and a number of these ultimate living units held together in a unitary reaction field.

5. Nutrition, holotrophic but without chlorophyll. This condition was soon advanced to the chloro-holophytic condition and from either level there arose parasitic and saprophytic bionts and organisms, and in the animal series eating organisms.

II. PROTOPHYTA. Organisms with protoplasts. Beginning of the problem of cell organization and evolution of multicellular, complicated living mechanisms.

6. The simplest unicellular condition consisting of a definitely organized reaction system or protoplast. Practically all organisms up to the highest plants and animals exist as separate cells in one or more stages of their life cycle. The cells in the first evolutionary stage have either no definitely organized nucleus or a nucleus without either nuclear membrane or definite chromosomes and without a typical karyokinesis.

7. The potentialities for the simpler physiological processes of the cell, as absorption, mobility of the protoplasm, irritability, etc.

8. Respiration, which is a fundamentally important process taking place in the active cells of all plants and animals.

9. Division of the cell as a whole, with perpetuation of like structures and potentialities in the daughter cells, alternating with resting periods.

10. Development of a cell wall, with cellulose or other chemical compounds.

11. Development of alternate phases of walled cells and naked cells in the life cycle, rarely lost in any plants except in a few of the Thallophyta.

12. The evolution of a more complex system of the protoplasm with highly organized nucleus, with nuclear membrane, chromosomes, nucleolus, etc.

13. Development of a definite chloroplast with chlorophyll.

14. With the potentiality for chlorophyll production, came also the process of photosynthesis with the usual formation of sugar, starch, etc. This process and the production of chlorophyll are sometimes partly or completely lost by the evolution of inhibitory factors.

15. With the evolution of a more perfectly organized nucleus and chromosomes, the typical karyokinesis and resting stage of the higher plants and animals was initiated.

16. Definite organization of the chromosomes and their equational division.

17. A special system for the separation of the daughter chromosomes, including spindle fibers, centrosomes, a definite polar organization, and polar radiations at each karyokinesis.

18. Evolution of a flagellate or ciliate motor system, present in at least one phase of the life cycle, in the main line of the plant series and apparently never lost until the stage of the more advanced seed plants. The ciliate condition was developed in some series at a very low evolutionary level as in bacteria, and on the other hand, there is no evidence apparently that it was ever developed in such lines as diatoms, conjugates and red algae.

III. NEMATOPHITA. Beginning of plants with sexuality.

19. Potentiality of sexuality with appearance of primary sexual states giving the property of attraction and fusion between isogamous gametes, the cells from time to time being in any of the three states—female, male, neuter.

20. The reduction division phase with synapsis of chromosomes. The sequences of fertilization, reduction, and the individual give rise to various types of life cycles.

21. Mendelian heredity as a result of fertilization and meiosis and exhibition of dominance and recessiveness in the diploid phase.

22. Multicellular condition, at first colonial, and with a restriction of separation of cells; in the main series developing a linear aggregate. In the highest plants the filament disappears or may be said to be restricted to the first two cells.

23. Attainment of heterogamy, through earlier determination in the cells of the sexual state.

24. Normal, higher type of heterogeny with extremely dimorphic gametes.

25. Correlative interaction of cells in the multicellular organism.

26. Differentiation system depending on physiological gradients in the multicellular body and a complexity of major and minor hereditary potentialities, not all of which are expressed at a given time or in a given cell.

27. Establishment of definite vegetative and reproductive phases in the process of differentiation, following a regular sequence in the usual ontogenetic cycle of the multicellular, differentiated plant body.

28. Development of base and apex of the filament and in the higher forms a base and apex in the growth of the solid aggregate individual.

29. Evolution of definite spermaries and ovaries and retention of the egg in the ovary.

30. Secondary sexual states in at least some of the body cells of the gametophyte causing secondary sexual dimorphism, through influencing hereditary expression, but not producing attractive properties as the primary states do in the gametes.

IV. PROTO-BRYOPHYTA. The great transition hiatus leading to the Metathallophyta. There are no known living or fossil plants which represent this evolutionary level.

31. Progression from a linear aggregate to mature solid aggregate, the filamentous condition being confined to the juvenile phase of the

gametophyte. The solid buds produce a dorsiventral or bilateral gametophyte in the main series which in some lines advance more or less to a radial symmetry again.

32. Evolution of an epidermis and distinct internal tissues in the gametophyte or sporophyte or in both.

33. Evolution of rhizoids on the gametophyte. The rhizoids disappear in the higher plants through the great reduction of the gametophyte.

34. Typical antithetic alternation of generations life cycle established with the twelve antithetic stages.

35. Gametangia organized into definite types of archegonia and antheridia, which undergo progressive reduction in the higher groups of plants.

V. BRYOPHYTA. The lower homosporous Meta-thallophyta.

36. Completely parasitic, enclosed, one-phased sporophyte.

37. Radially symmetrical condition of the sporophyte.

38. Two-phased sporophyte, the juvenile enclosed and the mature exposed condition.

39. Development of the ability for dehiscence of the sporangium. This is never lost in the main series except in the megasporangium of seed plants.

40. General fundamental potentiality complex through which the sporophyte develops four general regions or systems—(1) an absorption system, (2) a supporting and conducting system, (3) a photosynthetic system, and (4) a spore-reproductive system.

41. Transpiration established in the sporophyte, with stomata. This system is very rarely lost.

42. Potentiality for a very definite type of stomata, the general type continuing to the highest plants.

43. Development of lateral expansions or outgrowths in some of the highest mosses, as the hypophyses of Splachnums.

44. Evolution of a central strand in the sporophyte, shown in the higher plants as the embryonic plerome, as distinguished from the periblem or cortical tissue.

45. First stage, in the evolution, of the shifting of spore reproduction from the central axis to the periphery, by the development of a central columella in the sporangium of the higher Bryophytes.

VI. PROTO-PTERIDOPHYTA. Large transition hiatus leading to the homosporous vascular plants.

46. Two-phased sporophyte with parasitic and completely independent phases, the enclosed and exposed conditions still present in the parasitic phase, as in the Bryophytes.

47. Sinking of the archegonium venter into the tissues of the gametophyte. The horned liverworts of the Bryophyta also have sunken archegonium venters.

48. Potentiality for long-continued growth of the sporophyte.

49. Complete evolution of indeterminate growth of the sporophyte, the reproduction process not followed by immediate death. In the

higher plants this potentiality may be inhibited by the introduction of the annual habit.

50. Negative geotropism of the stem bud.

VII. PTERIDOPHYTA HOMOSPORAE. Completely evolved vascular plants with a two phased sporophyte and an indeterminate axis.

51. The normal vascular system, appearing in all the lines of higher plants, in the main evolutionary line with pith on the inside and cortex on the outside.

52. Highly evolved cambium system with secondary growth in thickness, in the main series. This potentiality is, however, reduced or lost in various phyletic lines but not in the main ones.

53. Potentiality for the production of typical leaves with a vascular supply.

54. Fundamental potentiality for the spiral development of the leaves in the sporophyte. This spiral growth reaction is present with various modifications in all living vascular plants, and apparently in some fossil Proto-Pteridophyta.

55. The complete centrifugal shifting of the reproductive process from the stem tip and central axis to the leaves.

56. Roots, originating at first as lateral organs and later as basal organs of the embryo.

57. Geotropism of roots.

58. Decided dorsiventrality of the leaves usually with phototropism.

59. Branching potentiality evolved which is normally monopodial in all living lines except in the Lepidophyta in which it is dichotomous and was apparently introduced in a very early Proto-Pteridophyte stage.

60. Dimorphism between sporophylls and foliage leaves attained on the higher levels.

VIII. PTERIDOPHYTA HETEROSPORAE. Attainment of the level in which sex determination takes place in the sporophyte.

61. Shifting of time of sex determination from the gametophyte to the sporophyte.

62. In consequence of shifting of time of sex determination both secondary male and female states developed in some part of the sporophyte, on the lowest level in the same sorus of a leaf.

63. In consequence of secondary sexual states in the sporophyte, dimorphic sporangia, sporocytes, and spores produced, microspores and megaspores.

64. Unisexual gametophytes, having their sex completely established in the spore before germination. The establishment of secondary sexual states before the time of the reduction division determines that there is no segregation of sex through the separation of the synaptic chromosomes but all the spores and the subsequent gametophytes coming from one sporocyte continue the sexual state previously established in the sporangium and sporocyte. Sex-reversal in heterosporous gametophytes is very rare.

65. Decided reduction in size of gametophytes, namely more prompt determination of cell lineage.

66. Very extreme dimorphism of the male and female gametophytes.

67. Earlier sex determination in the ontogeny, each sorus having but one secondary state developed.

68. Advance in time of sex determination to the incept of the sporophyll, resulting in dimorphism of sporophylls, megasporophylls and microsporophylls.

69. Decided reduction of the antheridium to a single unit in the male gametophyte.

70. Complete or nearly complete inhibition of chlorophyll development in the gametophytes which are dependent on the parent sporophyte through the food stored in the spores.

IX. GYMNOSPERMAE. Attainment of the seed habit, with parasitic gametophytes.

71. Retention of megaspores and microspores, with germination in the sporangia.

72. In consequence of spore retention, parasitic gametophytes.

73. Pollination process established.

74. Acquisition of a two-phased male gametophyte with development of the parasitic pollen tube in the ovule.

75. Ovules or megasporangia with integuments.

76. Resting stage of embryo intercalated between the parasitic and independent phases of the sporophyte, resulting in seed dormancy.

77. Abscission of fruit or seed.

78. Food storage, during development of the seed, in the embryo sporophyte or surrounding parasitic tissues or in both, which enables the embryo to become established as an independent plant in the process of sprouting.

79. Sprouting of the seed or renewal of growth activity in the sporophyte embryo, with complex reactions developed at this phase, not only an awakening from dormancy but various other activities, as the definite reaction to gravity, etc.

80. Increase in functional axillary bud development to a greater or less degree, giving rise, on the higher levels, to much branched systems, which may be simplified again in various higher series through a counter-evolutionary movement, as shortening the ontogeny to the annual condition, etc.

81. Determinate reproductive axis of the sporophyte, or flower potentiality, in all the higher series. The lowest fossil Gymnosperms are without flowers and a few living species still have indeterminate reproductive axes, while many of the Pteridophytes have flowers.

82. Extreme differentiation of tissues of carpel and stamen from leaf tissue, the carpels and other parts modified with them finally giving rise to the fruit.

83. Evolution of a standard type of embryo with radicle, plumule, and cotyledons.

84. Development of a peduncle below the flower, on the higher levels in various lines. This may be reduced again. Peduncles are also developed in some Pteridophytes.

85. Development of internodes in most of the higher series. These may be reduced again through new evolutionary movements. Some of

the lower groups, even of Homosporous Pteridophytes also have the internodal potentiality.

X. ANGIOSPERMAE. The extreme stage of complexity of fundamental potentialities, with closed carpels, stigmas and endosperm developing from a triploid or polypoid fusion nucleus.

86. Development of special complex types of xylem vessels in the vascular bundles.
87. Closing of the carpellate leaf, producing an ovulary.
88. Development of a stigma.
89. Potentiality for a very consistent type of microsporophyll, or stamen, normally with a filament and an anther with four microsporangia which are rarely reduced to two.
90. Very decided limitation of the growth of the gametophytes to an eight-celled female and a three-celled male condition, as the usual type in most groups.
91. In nearly all cases a three-celled egg-apparatus, which apparently represents a vestigial archegonium.
92. Development of the pollen tube through the stigma, style, open cavity of the ovulary, and the micropyle. This condition sometimes modified by the introduction of chalazogamy.
93. Evolution of nonciliated spermatozoids. This condition is also attained in the higher phylum of the Gymnosperms, the Strobilophyta.
94. Triple or multiple fusions within the female gametophyte resulting in a primary endosperm nucleus in addition to the diploid oospore.
95. Triploid or occasionally polyploid endosperm or xeniophyte.
96. Potentiality for a definite gradient in the bisporangiate flowers, causing male expression first, and followed by a sex-reversal to female expression. This is modified in many lines by the progression in the time of sex-determination to moneciousness and dieciousness, but commonly with vestigial development of the opposite set of sporophylls.
97. Potentiality for the development of a perianth which is rarely completely lost through the progressive evolution of the determinateness of the flower. There is a slight development of the perianth in some groups of Pteridophytes and Gymnosperms.
98. Differentiation of the perianth into a distinct calyx and corolla, except in some of the lowest types and some of the advanced, reduced types of flowers.
99. Evolution of an inflorescence in all but the lowest types. This is occasionally reduced again to a solitary flower in some of the advanced lines.
100. Union of the carpels into a gynecium with a compound ovulary in all except the lowest members of the various phylogenetic series. The ovulary is usually plurilocular in the lower levels and unilocular in the higher levels.

One may wonder as to what is the fundamental cause of this remarkably consistent, progressive accumulation of fundamental modes of reaction. Whatever the cause, this accumulative, irreversible series gives a definite picture of the primary evolutionary process. It shows that evolution in its fundamental aspects is an intrinsic and definitely kinetic process and that there is a principle of stability involved as well as a principle of change. It also shows that the plant kingdom as a whole is a direct contradiction of the old teleological hypotheses of evolution as contained in Buffon's direct response to environment, Lamarck's use and disuse, and Darwin's natural selection. It also is plainly a contradiction of some of the newer genetic hypotheses which attribute the primary cause of evolutionary action to the effect of various kinds of radiations on the cell, such as cosmic rays, violet rays, X-rays, etc. These universal physical agents have been active during the geological ages and must have hit every susceptible particle of protoplasm of all plants myriads of times, and if they were primary causal agents we should either have a plant kingdom of a single species or a haphazard, anarchistic taxonomic system; which is a direct contradiction of the actual evolution which has taken place.

When one has ascertained the fundamental potentialities for each subkingdom, one may proceed to catalog all the potentialities or characteristics contained in each phylum or class or other group in addition to the accumulation common to the entire subkingdom in which the phylum or class has its basis. This has not been attempted, but to illustrate the way the method can be used in determining the evolutionary level to which any species has attained a list of the total potentialities or characteristics possessed by the species may be made. Some of these potentialities may be simple Mendelian genes. The writer has attempted to catalog thirty-four species in this manner, a summary of which is presented in the chart given below. Eight of these summations are here presented to illustrate the progression of complexity from the lowest to the highest level.

No claim is made that these summations are complete, for a complete summation will require an enormous amount of study of each species. However, an attempt has been made to study the different species on the same general basis and thus the series of numbers for the eight examples given—16, 42, 68, 95, 122, 140, 170, 200—does clearly indicate each species' position in the taxonomic scale. A similar method can be used to determine the relative position of the genera or species in a group in relation to each other if they are to be arranged in the order of their evolutionary complexity as higher or lower types.

Nitrosococcus nitrosus Mig.

This is an autotrophic bacterium belonging to the Coccaceae and represents the lowest type of organism. This autophyte was isolated from the soil of Quito, Ecuador, South America, by Winogradsky.

Phylum, Schizophyta; class, Schizomycetae; order, Bacteriales; family, Coccaceae.

I. The first ten of the one hundred enumerated potentialities of the general accumulative list.

II. The special potentialities accumulated in the species.

11. The specific type of autrophic reaction deriving energy through oxidizing ammonia to nitrite and obtaining carbon from the atmospheric carbon dioxide.

12. The spherical or coccus shape, which is the simplest shape of a bit of colloidal protoplasm surrounded by a wall.

13. Specific size of the rather large cells, with a diameter of 1.4–1.7 microns.

14. Non-motile condition—no motile stage known. The absence of cilia represents the simplest, most primitive condition of the living cell.

15. Apparent absence of a zooglea stage, always growing as free cells without special pigment formation. This represents the simplest cellular condition imaginable.

16. Potentiality for a special physiological condition—an obligate aerobe.

The first ten conditions are fundamental potentialities common to all higher organisms. In the higher, however, there is a definite nucleus with a more complex structure. *Nitroscoccus nitrosus* has apparently only six special characteristics, and even of these two appear quite generally in the life cycle of higher organisms, namely the spherical, free cell condition and the non-motile condition.

Sphaerella lacustris (Girod.) Wittr.

This active unicellular alga is often abundant in rain water pools and often colors these a bright red because of the development of haematochrome in its cells.

Phylum, Gonidiophyta; class, Chlorococceae; order Volvocales; family, Chlamydomonadaceae.

I. The first twenty-one of the one hundred general potentialities.

II. The accumulation of special potentialities in the species.

22. Potentiality giving motile and no-motile vegetative cells in the ontogeny.

23. Flagella developed in the motile stage or zoospores.

24. The definite biciliate condition of the zoospores and gametes.

25. Centrosomes present, the dynamic centers of the flagella, spindle poles, and polar radiations.

26. An eye spot in the active cells.

27. Spherical shape of the resting cells.

28. Oblong-ovoid shape of the gametes.

29. The resting zygote.
30. Cuticularized wall of the zygote.
31. Potentiality for the red coloring matter or haematochrome.
32. Pointed ciliate end of the zoospores with two minute openings in the cellulose wall.
33. Peculiar, loose cell wall of the zoospore with protoplasmic strands passing to the protoplast within.
34. Characteristic size of the cells of the species.
35. Characteristic size and shape of the bell-shaped chloroplast.
36. A pyrenoid in the chloroplast.
37. Long resting stage or dormancy under dry conditions without loss of vitality.
38. Gelatinous pectose in the cellulose wall.
39. Power of dissolving the cell wall at certain points.
40. Definite reaction to light.
41. Characteristic swarming of the gametes in the water.
42. Diploid number of chromosomes in the zygote, with the reduction division during its germination.

Riccia fluitans L.

This species is a simple liverwort growing in the water or on wet banks.

Phylum, Bryophyta; class, Hepaticae; order, Marchantiales; family, Ricciaceae.

I. The first thirty-eight potentialities of the general series.

II. The special potentialities accumulated in *Riccia.*

39. Potentiality determining the slender thalloid form of the gametophyte.
40. Gametophyte conditioned to live in fresh water.
41. Dichotomous branching.
42. Adventive branches from ventral sides of the thallus in the floating form.
43. Several distinct tissue layers in the thallus.
44. Thallus with a median furrow.
45. Development of large air cavities.
46. Dorsal epidermis of thallus.
47. Small openings in the epidermis to the air chambers in the terrestrial form.
48. Ventral scales in a row.
49. Double row formed by rupturing of the ventral scales.
50. Characteristic form of the scales.
51. Rhizoids with a smooth inner surface.
52. Tuberculate rhizoids.
53. Violet color of the ventral scales and the margins of the thallus.
54. Hermaphroditic condition of gametophyte.
55. Characteristic antheridia.
56. Archegonia with stalk, venter, neck, and lid cells.
57. Special division of the egg mother cell to form the egg and ventral canal cell.

58. Spherical form of the egg.
59. Dissolving of the neck canal cells and the ventral canal cell.
60. Opening of the lid cells of the neck.
61. Antheridia and archegonia immersed singly in cavities of the dorsal surface, scattered in the thallus.
62. Prominent antheridial ostiole.
63. Biciliate spermatozoids which swim down the necks of the archegonia.
64. Spherical sporophyte in the venter.
65. Ventral protuberance of the thallus, produced by the growth of the sporophyte.
66. Complete transformation of the inside of the sporophyte into sporocytes and spores.
67. Characteristic, large spores with aerolate surface.
68. Disappearing of the epidermal wall of the sporophyte (sporangium) at the maturing of the spores.

Ophioglossum vulgatum L.

The adder-tongue fern represents about the simplest condition of the living vascular plants, at least of those belonging to the Ptenophyta.
Phylum, Ptenophyta; class, Phyllopteridae; order, Ophioglossales; family, Ophioglossaceae.

I. The first fifty-nine fundamental potentialities of the general series.

II. Accumulation of potentialities in the *Ophioglossum* series.

60. A short, nearly erect, slow-growing retreating rhizome.
61. Character of the cortex of the rhizome.
62. Distinctive type of vascular bundles with characteristic wood cells.
63. Characteristic shape of foliage leaf.
64. General size of leaf.
65. Evolution of petiole.
66. Characteristic type of bud on the rhizome.
67. Potentiality for reticulate or arceolate venation.
68. Several vascular bundles in base of leaf.
69. Erect vernation of leaves.
70. Distribution of stomata.
71. Succulent texture of plant.
72. Slender fleshy roots, occasionally with dichotomous branching.
73. Specific structure of the roots.
74. Sporophyll with distinct sporangiophore on upper side.
75. Long stalk of sporangiophore.
76. Characteristic round sporangia.
77. Sporangia in two rows on sporangiophore.
78. Characteristic dehiscence of bivalved sporangia.
79. Characteristic shape and size of spores.
80. Yellow color of spores.
81. Germination of spores to form a small characteristic protonema.
82. Potentiality for subterranean growth of gametophyte.
83. Bean-shaped character of gametophyte.

84. Thick, fleshy texture of gametophyte.
85. Potentiality inhibiting the development of chlorophyll in gametophyte.
86. Mycorrhizal relation with a fungus, giving phagophytic nutrition.
87. Character of the rhizoids on gametophyte.
88. Hermaphroditic condition of gametophyte.
89. Short neck of archegonium.
90. Lid cells of archegonium.
91. Division of mother cell into the egg and ventral canal cell.
92. Neck canal cells and ventral canal cells dissolving.
93. Characteristic antheridia.
94. Large, spirally coiled, multiciliate spermatozoids.
95. Characteristic bryophyte type of embryo development, the inner of the first two cells of the embryo giving rise to the foot and the outer one to the first leaf, bud and root.

Marsilea quadrifolia L.

The European *Marsilea* is commonly cultivated in greenhouses and botanic gardens and occasionally escapes into favorable habitats. It is the lowest type of the living, leptosporangiate heterosperous ferns.

Phylum, Ptenophyta; class, Hydropteridae; order, Marsileales; family, Marsileaceae.

I. The first seventy fundamental potentialities of the general series, except No. 60.

II. The accumulation of special potentialities in the *Marsilea* line.

70. Highly evolved creeping, rapidly growing rhizome.
71. Potentially fitting the plant for a moist ground of aquatic habitat.
72. Potentiality for internodes between the leaf nodes.
73. Characteristic vascular system with absence of secondary thickening.
74. Characteristic cortex of the rhizome.
75. Sporadic monopodial branching of the rhizome.
76. Characteristic type of roots.
77. Structure of the roots.
78. Reaction to gravity and substratum of the rhizome.
79. Foliage leaf with four leaflets.
80. Long slender petiole.
81. Structure of the petiole.
82. Shape and size of the leaflets.
83. Structure and venation of leaflet.
84. Smooth upper surface of leaflet and slightly hairy lower surface.
85. Distribution of stomata.
86. Reaction to darkness and light, the leaflets folding up like a fan and also nutating with the sun at least in *M. vestita*.
87. Special type of sporophyll, having a special primary dichotomy, the one branch being vegetative, the other reproductive.

88. Usually a single dichotomy of the reproductive branch of the sporophyll.

89. Special length of petiolule bearing the sporocarps.

90. Closing up of the reproductive leaflet and complete fusion of its two valves to form the sporocarp.

91. Yellowish-brown hairs on the petiolules of the sporocarps.

92. Characteristic shape and size of sporocarp, with two teeth at its base.

93. Smooth surface of sporocarp.

94. Hard texture of the mature sporocarp.

95. Internal organization of the sporocarp into eight or nine sori or compartments in each of the two valves.

96. Potentiality for the transformation of the internal tissues of the sporocarp into a gelatinous mass which comes out as a gelatinous cord, bearing the two types of sporangia, when the sporocarp breaks open by two valves in the water.

97. Potentiality which determines the comparative number and distribution of megasporangia and microsporangia in each sorus.

98. Characteristic time of sex-determination in the incipient sporangia.

99. Shape and size of the megasporangium.

100. Cellular structure and shape of the megasporangium.

101. Short thick stalk of the megasporangium.

102. Character of the single surviving megaspore as to shape, size, and surface.

103. Potentiality which causes the destruction of several megaspores during the growth of the surviving megaspore.

104. Character of the abundant supply of starch grains in the megaspore.

105. Spherical shape and small size of the microsporangium.

106. Long slender stalk of the microsporangium.

107. Cellular structure of microsporangium.

108. Abundant number of microspores in a microsporangium.

109. Character of the microspores as to shape, size, and surface.

110. Characteristic development of the female gametophyte in one end of the megaspore.

111. Characteristic opening of the end of the megaspore and the protrusion of the neck of the archegonium.

112. Simple character of the cellular structure of the female thallus.

113. Lack of chlorophyll in the male gametophyte and young female gametophyte.

114. Character of the archegonium with very short neck.

115. Abundant funnel-like mass of gelatinous material coming from the neck of the archegonium into which the spermatozoids swim.

116. Characteristic small male gametophyte developed in the microspore.

117. Cellular structure of the male gametophyte.

118. Very small and reduced antheridium, producing only a few spermatozoids.

119. Bulging out and breaking open of the microspore wall next to the tip of the antheridium through which the spermatozoids escape.

120. Characteristic, large, spirally coiled, multiciliate spermatozoid.
121. Characteristic embryogeny.
122. General character of the young sporophyte with one cotyledon.

Araucaria araucana (Molina) K. Koch.

The Monkey-puzzle-tree represents a primitive conifer type, as indicated by its broad, spirally arranged leaves, its intermittent, rhythmically developed zones of main branches with very coarse ultimate branchlets, and its very primitive type of flowers.

Phylum, Strobilophyta; class, Coniferae; order, Araucariales; family, Araucariaceae.

I. The first eighty-three fundamental potentialities of the general accumulative series.

II. The special potentialities of the *Araucaria* series.

84. Sperms without cilia.
85. Ovules developing without a pollen-chamber.
86. Ovules imbedded in the lower part of the carpel.
87. One ovule for each carpel.
88. Peculiar growth of pollen tube through the carpel tissue.
89. Greater growth of pollen tube as compared with Cycadophyta.
90. Flower production shifted beyond the primary stem axis.
91. Special type of spiral systems in the flowers.
92. Flowers monosporangiate.
93. Diecious condition.
94. Characteristic staminate cone.
95. Leaf-like stamens.
96. Stamens with numerous pollen-sacs.
97. Character of wall of the slender pollen-sac.
98. Characteristic ovoid carpellate cone.
99. Shape and size of carpel.
100. Texture of carpel.
101. Special small ligule on the carpel.
102. Character of ripe carpellate fruit.
103. Characteristic size and shape of pollen-grain.
104. Male gametophyte with numerous vegetative nuclei.
105. Characteristic female gametophyte, originating in a large number of free cells.
106. A number of archegonia in each female gametophyte.
107. Characteristic archegonium with twelve neck cells.
108. Egg and short-lived ventral canal cell.
109. Characteristic embryogeny.
110. Embryo with two cotyledons.
111. Vascular supply of each cotyledon.
112. Seed dry and large.
113. Character of the testa of the seed.
114. Elongated shape of mature seed.
115. Characteristic mode of sprouting.
116. Thickening of the hypocotyl.
117. Type of the spiral arrangement of the leaves.

118. Rhythmical development of zones of branches of the main stem.
119. Meager development of axillary buds.
120. Very robust ultimate twigs.
121. Large broad leaves.
122. Characteristic parallel venation with dichotomy.
123. Smaller leaves in resting zones.
124. Firm thick texture of leaves.
125. Distinctive character of stomata.
126. Abscission of ultimate twigs.
127. Resin passages in the leaves.
128. Highly efficient cambium, producing a large wood cylinder.
129. Wood with uniform tracheids.
130. Tracheids with multiseriate bordered pits, and with spiral thickenings in the primary wood.
131. Characteristic medullary rays one cell in width.
132. Resin produced in the medullary rays and in passages in the roots and bark.
133. Double leaf-traces persistent in the secondary wood.
134. Rather large pith in contrast with other conifer groups.
135. Characteristic outer bark.
136. Cork cambium.
137. Characteristic structure of inner bark.
138. General characteristics of the wood, as strength, fracture, and durability.
139. Development of a tap-root.
140. Branching system of roots.

Magnolia acuminata L. Cucumber Magnolia.

The Magnolia is one of the most primitive types of Dicotyls, although it is probably considerably advanced over the form which must have represented the original ancestral simple tree.

Phylum, Anthophyta; class, Dicotylae; order, Ranales; family, Magnoliaceae.

I. The ninety-eight fundamental potentialities of the general accumulative series.

II. The special potentialities accumulated in the Cucumber Magnolia.

99. Highly evolved woody stem system.
100. Resting vegetative bud.
101. Netted-veined character of leaves.
102. Pinnate venation from a prominent midrib.
103. Dichotomy of the main lateral veins.
104. Characteristic branching habit.
105. Development of a cork cambium.
106. Characteristic type of outer bark.
107. Characteristic inner bark.
108. Rather large pith.
109. Soft texture of pith.
110. Characteristic root system.
111. Branching of roots.

112. Development of root hairs.
113. Reduction of spiralization to a 2–3–5–1 leaf spiral on the vegetative stem.
114. Characteristic length of internodes.
115. Large stipules.
116. Connate condition of stipules.
117. Stipules extending completely around the stem.
118. Silky pubescence on the stipules.
119. Abscission of stipules.
120. Conduplicate folding of leaf in the bud.
121. Characteristic shape of leaf.
122. Characteristic size of leaf.
123. Entire margin of leaf blade.
124. Leaf blade with minute transparent dots.
125. Pubescence on lower side of leaf.
126. Petiole of leaf.
127. Abscission of leaf.
128. Numerous bundle-scars in leaf scar.
129. Characteristic stipular rings on twigs.
130. Bitter aromatic bark.
131. Characteristic, nearly glabrous peduncle of flower.
132. Three-parted perianth.
133. Differentiated calyx and corolla.
134. Double cycle of petals.
135. Characteristic shape and size of sepals.
136. Texture of sepals.
137. Characteristic shape and size of petals.
138. Texture of petals.
139. Greenish-yellow color of petals.
140. Glaucous condition of perianth and gynecium.
141. Deciduous perianth segments.
142. Characteristic shape and size of carpels.
143. Carpels cohering together.
144. Characteristic spiral condition of carpels in gynecium.
145. Shape and size of stamens.
146. Characteristic spiral condition of stamens in andrecium.
147. Color of stamens.
148. Shape of microsporangia.
149. Characteristic shape and size of pollen.
150. Color of pollen-grains.
151. Fragrance of the flowers.
152. Carpels forming follicles.
153. Each carpel with two ovules.
154. Ovules anatropous.
155. Characteristic wall of follicles.
156. Rose color of mature cylindric cone of carpels.
157. Dehiscence of follicles.
158. Fleshy outer seed coat.
159. Red color of seed coat.
160. Bony inner seed coat.

161. Thread-like slender funiculus of seed.
162. Persistence of follicles on the receptacle of the fruit.
163. Fleshy endosperm.
164. Characteristic embryogeny.
165. Very small embryo.
166. Characteristic sprouting of embryo.
167. Wood with distinct heartwood and sapwood.
168. Characteristic medullary rays.
169. Wood diffuse porous.
170. Soft, light character of the wood.

Taraxacum officinale Weber. (*Leontodon taraxacum* L.). Dandelion.

The dandelion is one of the most highly evolved plants and represents the main culmination type in the plant kingdom.

Phylum, Anthophyta; class, Dicotylae; order, Compositales; family, Cichoriaceae.

I. The one hundred general fundamental potentialities.

II. The special potentialities accumulated in the Dandelion series.

101. The change from the more primitive type of stem to the low herbaceous type.
102. The evolution of a typical perennial rosette.
103. Netted-veined leaves.
104. Prominent midvein and weak lateral veins of the pinnately veined leaves.
105. Characteristic angiospermous embryogeny.
106. Two cotyledons.
107. Primitive spiral to cyclic condition of flower.
108. Tetracyclic condition of flower.
109. Syncarpous condition.
110. Advanced determinate condition of the floral axis resulting in epigyny.
111. Change from plurilocular to unilocular ovulary.
112. Single ovule and seed in ovulary.
113. Anatropous ovule from original orthotropous type.
114. Shifting of flowers away from the primary axis to the axillary position.
115. Disk or head evolved, an extremely determinate inflorescence axis.
116. Double condition of involucral bracts around the disk.
117. Characteristic size and shape of the outer bracts.
118. Characteristic size and shape of the inner bracts.
119. Characteristic texture and structure of the bracts.
120. Reflexing of involucral bracts at maturity; two periods, the outer first.
121. Suppression of the leaf bracts subtending the individual flowers.
122. Characteristic white epidermal layer on top of the disk.
123. Very small flowers.
124. Reduction of stigmas to two.
125. Minutely papillose surface of stigmas.

126. Coiling of stigmas.
127. Sympetalous condition of corolla, the original free petal condition still represented by the vestigial corolla lobes.
128. Tubular shape of corolla.
129. Texture of corolla.
130. Zygomorphic corolla with strap-shaped condition.
131. Centripetal split of the inner sides of the corollas, giving radial symmetry to the head.
132. Yellow color of corolla.
133. Outer ligulate corollas with broad purplish band beneath, the inner ones without such band.
134. Characteristic stamens with delicate filaments.
135. Sagittate anthers.
136. Union of stamen filaments with corolla.
137. Union of anthers, or synantherous condition.
138. Characteristic pollen grain.
139. Color of pollen.
140. Minute pedicel of flower.
141. Pappus development, replacing calyx.
142. Characteristic simple nature of individual pappus bristles.
143. Nectar gland in flower.
144. Characteristic nectar excreted.
145. Complex leaf reaction during the ontogeny, giving a succession of leaf types.
146. Juvenile leaf shape.
147. Lobed leaf type of the older plant.
148. General size of leaf.
149. Characteristic texture of leaf.
150. Characteristic leaf margin.
151. Soft narrow teeth on the lobes.
152. Flat, sheathing leaf base.
153. Lactiferous vessels.
154. Secretion of latex with bitter principle.
155. Margined petiole.
156. Hollow peduncle or scape.
157. Characteristic texture of the peduncle.
158. Property for great elongation of the peduncle in suitable environment to three feet or more.
159. Hollow petiole and midrib.
160. Delicate hairs on the leaf blade.
161. Long silky hairs at base of petiole.
162. Characteristic shape of roots.
163. Characteristic texture of roots.
164. Branching of roots.
165. Special longitudinal segmentation of the old main root.
166. Special reproductive ability of roots, any little piece being able to develop a new plant.
167. Root hairs on root tips.
168. Fruit an achene.
169. Development of parachute neck or strand at top of achene.

170. Shape of mature achene.
171. Characteristic texture of achene wall.
172. Prominent conical beak on the achene.
173. Special ribs and grooves on the achene.
174. Prominent projections, especially at the upper part of the achene.
175. Color of achene.
176. Hygroscopic closing and opening of pappus bristles in wet and dry conditions.
177. Shape and size of stem.
178. Slow growth of stem producing the leaf rosette.
179. Characteristic cortical region of stem.
180. Definite physiological gradient in the growing bud giving five kinds of stem development in succession: 1, the rosette stem; the peduncle; 3, the disk; 4, the pedicel; 5, the cortical stem tube from which the ovulary is developed.
181. Special vascular system in the rosette stem.
182. Arrangement of vascular bundles in the peduncle.
183. Vascular supply in the expanded disk.
184. Nature of the vascular system in the pedicel.
185. Characteristic spiral phyllotaxy in the rosette.
186. Spiral arrangement of flowers on the disk.
187. Closing of flower heads in the dark and in low temperature.
188. Potentiality interfering with complete sexualization of chromosomes, producing imperfect synapsis at reduction.
189. Irregularity of reduction in the anther.
190. Regularity of partial synapsis in the ovule, giving rise to diploid megaspores.
191. Characteristic shape and size of the one functional megaspore, with dissolution of the three vestigial megaspores.
192. Characteristic diploid female gametophyte arising from the diploid megaspore.
193. Characteristic egg apparatus with diploid egg.
194. Parthenogenetic development of the diploid egg.
195. Interference with Mendelian hereditary transmission because of diploid parthenogenesis.
196. General nature of endosperm development.
197. Characteristic mature embryo sporophyte.
198. Characteristic sprouting of the seed.
199. The character of the seedling cotyledons.
200. Potentiality to produce anthocyanin, especially in the young plant.

Summary of Accumulation of Potentialities in Thirty-four Species of Plants

Name of Plant	General Potentialities	Special Potentialities	Total
Nitrosococcus nitrosus Mig.	10	6	16
Rivularia echinulata (Smith) B. & F.	11	22	33
Scenadesmus quadricauda (Turp.) Breb.	17	11	28
Sphaerella lacustris (Girod.) Wittr.	21	21	42
Spirogyra reflexa Trans.	21	18	39
Puccinia graminis Pers.	26	29	55
Dictyophora phalloides Desv.	26	32	58
Chara crassicaulis Schleich.	30	32	62
Polysiphonia variegata (C. Ag.) J. Ag.	29	35	64
Riccia fluitans L.	38	30	68
Frullania asa-grayana Mont.	39	41	80
Archidium ohioense Schimp.	40	35	75
Polytrichum commune L.	45	40	85
Ophioglossum vulgatum L.	59	36	95
Onoclea sensibilis L.	60	45	105
Equisetum arvense L.	60	51	111
Marsilea quadrifolia L.	69	53	122
Selaginella krussiana (Kunze) A. Br.	70	55	125
Cycas revoluta Thunb.	84	59	143
Zamia integrifolia Ait.	84	65	149
Araucaria araucana (Mol.) K. Koch.	83	57	140
Taxodium distichum (L.) Rich.	84	69	153
Pinus radiata D. Don.	83	88	171
Ephedra viridis Cov.	85	95	180
Echinodorus cordifolius (L.) Gris.	99	71	170
Vallisneria spiralis L.	100	80	180
Zea mays L.	100	85	185
Iris germanica L.	100	89	189
Tipularia unifolia (Muhl.) B. S. P.	100	92	192
Magnolia acuminata L.	98	72	170
Viola papilionacea Pursh.	99	84	183
Salvia pitcheri Torr.	100	86	186
Salix interior Row.	100	85	185
Taraxacum officinale Weber.	100	100	200